PB87-157657

RCRA (Resource Conservation and Recovery Act) Guidance Document: Landfill Design, Liner Systems and Final Cover

(U.S.) Environmental Protection Agency
Washington, DC

7 Jul 82

U.S. Department of Commerce
National Technical Information Service
NTIS

PB87-157657

D R A F T

R C R A G U I D A N C E D O C U M E N T

L A N D F I L L D E S I G N

L I N E R S S T E M S A N D F I N A L C O V E R

[TO BE USED WITH RCRA REGULATIONS
SECTIONS 264.301(a) AND 264.310(a)]

I S S U E D: 7/ /82

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA 22161

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No. PB87 157657/AS
4. Title and Subtitle: RCRA Guidance Document, Landfill Design Liner Systems and Final Cover			5. Report Date: July 7, 1982
			6.
7. Author(s): Staff Office U.S. EPA			8. Performing Organization Rept. No.
9. Performing Organization Name and Address: Office of Solid Waste, U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, D.C. 20460			10. Project/Task/Work Unit No.
			11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address: U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, D.C. 20460			13. Type of Report & Period Covered: Guidance Manual 1982
			14.

15. Supplementary Notes

To be used with RCRA Regulations, Sections 264.301(A) and 264.301(A)

16. Abstract (Limit: 200 words)

This guidance document presents landfill design specifications which the Agency believes comply with the design and operating requirements of §264.301(A), and the closure requirements of §264.310(A) of the RCRA landfill regulations. These regulations have been formulated with the goal of eliminating the escape of leachate from landfills for all time to the extent practical.

The Agency wishes to emphasize that the specifications contained herein are guidance, not regulations.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unclassified	Unclassified	33
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI-Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

A. Purpose and Use

This guidance document presents landfill design specifications which the Agency believes comply with the the Design and Operating Requirements of §264.301 (a), and the Closure Requirements of §264.310(a) of the RCRA landfill regulations. These regulations have been formulated with the goal of elimin ating the escape of leachate from landfills for all time to the extent practical. Given that few things work perfectly or work for all time, absolute prevention of escape for all time is probably not realistic. However, the regulations require landfills to come as close to the containment ideal as possible. The Agency believes containment is practical during the operating life of most facilities of damage to the containment system occurs. After closure, minimization of leachate formation and escape is the best that current technology can practically achieve.

The regulations provide that landfills be equipped with liner and leachate collection systems capable of preventing release of leachate to the environment during the operating life of the unit and that a final cover designed to minimize release of pollutants be installed at closure. To provide flexibility, the design and operating characteristics required are expressed in terms of performance standards for system components as a whole. Optimally, these standards would contain numeric limits to the performance required of each system component, and most, but not all, of the currently promulgated standards are

expressed in numeric terms. For others, minimum specifications are not included. For example, though a final cover must be incorporated, the required capabilities of that system are currently expressed in performance terms such as "provide long-term minimization of the migration of liquids". The Agency intends to augment the general statements currently in the regulations by applying numeric limits to the performance required of each component. But, there will still be substantial flexibility in designing facilities to meet the standard and substantial uncertainty involved in judging whether a given design will, in fact, achieve the performance level prescribed.

This document provides specific designs the Agency believes accomplish the performance standards in the regulations. Permit applicants designing their facilities in accordance with the specifications contained herein, will be considered in compliance with §§264.301(a) and 264.310(a). If these specifications and procedures are followed, a draft permit will be issued. (Final permits cannot be issued until input from the public participation process is evaluated.)

The Agency wishes to emphasize that the specifications contained herein are guidance, not regulations. The Agency is not requiring, and does not intend, that all landfills be built in this way. On the contrary, the Agency believes there are many designs which can be acceptably used, depending on waste characteristics and location. Owners or operators wishing to use a different design, may demonstrate compliance with

§§264.301(a) and 264.310(a) directly to the permitting official. The specific design must provide the same level of performance as the design incorporated in this guidance under similar circumstances (waste characteristics, location, rainfall, etc.). For example, the specifications for leachate, collection, and removal systems in this guidance call for at least 30 centimeters (12 inches) of permeable drainage material with a minimum hydraulic conductivity of 1×10^{-3} cm/sec and a minimum slope of 2%. These specifications fulfill, in part, the regulatory requirement of §264.301(a)(2) that the design utilized "ensure that the leachate depth over the liner does not exceed 30 cm (one foot)." An applicant could show that other drainage his material, in combination with other design features, would result in the same leachate depth on the liner system as the design specifications contained in this guidance The Agency will accept convincing demonstrations of equivalency as compliance with the performance statements of §§264.301(a) and 264.310(a).

This document contains only initial guidance--it will be expanded over time to include additional designs and specifications which the Agency believes acceptably comply with the performance requirements of the regulations. The Agency recommends the liner specifications contained in this document for installation above the water table, work is underway on similar specifications for location in saturated soils. EPA will issue this additional guidance in the near future.

This document will also be expanded by incorporating the experience gained in implementing the performance standards.

The document is arranged according to the section of the regulation to which it corresponds. Those wishing to send technical information or suggestions concerning this document should address them to: Chief, Land Disposal Branch, Office of Solid Waste (WH-564), U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, D.C. 20460. EPA is particularly interested in information and suggestions concerning the usefulness of the document, expansion of it, and the effectiveness of the guidance contained in ensuring compliance with the performance requirements in the regulations.

EPA is also producing a series of Technical Resource Documents (TRD's), two of which address final cover and liners. The TRDs are designed to present the information and experience gained by the Agency over the years on a given topic. The TRDs as technical background or documents supporting these guidance documents and the regulations. Based partly on the information contained in the TRD's, the Agency made the policy decisions which resulted in the regulations and these guidance documents. TRD's corresponding to the guidance in this document are:

(1) Evaluating Cover Systems for Solid and Hazardous Waste (SW-867) NTIS Publication No. PB-81-166-340.

(2) Lining of Waste Impoundment and Disposal Facilities (SW-870) NTIS Publication No. PB-81-166-365.

(3) Landfill and Surface Impoundments Performance Evaluation (SW-869) NTIS Publication No. PB-81-166-357

These documents can be obtained from the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161. The Agency plans to publish amended versions of these documents in the fall of 1982.

B. Liner System Function, Components, and Life

1. The Regulations

The regulations require the system to function through scheduled closure and to consist, at a minimum, of a leacnate collection and removal system and at least one liner. The function of the leachate collection and removal system is to minimize the head (depth) of leachate on the liner. It must be capable of keeping the leachate head to 1 foot or less. The liner must be designed and constructed to prevent migration of liquids and must allow no more than de minimis infiltration of liquids into the liner itself.

2. Guidance

(a) Liner systems should be constructed wholly above the seasonal high water table, i.e., in the unsaturated soil.

(b) Landfill cells (i.e., units or discrete parts) should be designed with an system consisting of the following, as a minimum:

(1) A leachate collection, and removal system; and

(2) A synthetic liner with appropriate chemical resistance

(c) Where final cover will not be applied to landfill cells for 30 or more years after first placement of wastes, the liner

system should consist of the following, as a minimum:

(1) A leachate collection and removal system;

(2) A primary synthetic liner; and

(3) A leak detection system; and

(4) A secondary soil liner (e.g., clay).

3. Discussion

These designs are specifically recommended for installation in the unsaturated zone. A case-by-case demonstration of containment will be necessary for landfills located wholly or partially in the saturated zone.

In developing the this guidance, the Agency has chosen designs which come as close as possible to complete containment of leachate for as long as the unit is in operation. The Agency's designs are based on conventional technology, utilizing readily available equipment and materials, at practical costs.

Essentially complete containment is practical using the synthetic liners. However, experience with synthetic liners in contact with chemicals is relatively recent. Predictions based on chemistry, laboratory testing, and limited real world experience are sufficient to convince the Agency that containment for at least 30 years is practical, utilizing a single synthetic liner. The liner material must be tested for resistance to the chemicals to be contained and proper design and installation practices must be followed. Therefore, a single synthetic liner system is appropriate for cells which will receive final cover in less

than 30 years The Agency believes this will include most hazardous waste landfills since closure of individual trenches or cells is usually performed as they are filled, generally in five years or less.

If final closure is not scheduled for 30 years or more, a double liner system incorporating a top synthetic liner, a secondary soil based liner, with a leak detection system between the two liners is appropriate. The leak detection system is in addition to the leachate collection and removal system installed above the synthetic liner. When and if the secondary liner ever comes into use the leak detection system between the liners will reduce the liquid head on the secondary soil liner, thus reducing the rate of liquid transmission to the surrounding area.

Some clay soils can be placed and compacted to produce a liner system of very low permeability. Movement of liquids through well constructed clay liners is very slow. The release of leachate that contains hazardous constituents to the ground water and surrounding soil, is minimized but not prevented. The Agency is concerned that pollutants entering the pore structure of the clay during site life will be released over time. Synthetics, on the other hand, are essentially 100 percent effective, in rejecting leachate reaching the liner surface. The leachate is then removed by the leachate collection system and is thus prevented from escaping to the subterranean environment. The Agency realizes that very small amounts of

liquid may enter the structure of synthetic membranes causing them to swell, but the amount is negligible and leads to no future ground water contamination. In sum, the Agency believes that clay liners are valuable as a backup to synthetic liners and as an extra measure of protection in all cases. Where final cover will not be applied for more than 30 years, however, a secondary clay liner as a backup, should be provided the synthetic primary liner deteriorate.

EPA realizes that there is disagreement as to the relative effectiveness of various types of liners. The Agency is, therefore, seeking data and information concerning:

(1) The relative efficiency of synthetic, soil, and other liners in preventing and minimizing the transmission of liquids and the release of pollutants;

(2) The effective life of various liner designs;

(3) The causes of physical and chemical damage to various liners and how damage can be avoided;

(4) The effect of synthetic and soil liners on the efficiency of leachate collection systems;

(5) The potential for saturated soil liners to attenuate pollutants;

(6) The potential for soil liners to release pollutants after proper closure has reduced the amount of leachate formed; and

(7) The benefits to be realized and the risks posed by various liner designs.

C. Leachate Detection, Collection, and Removal Systems

1. The Regulations

The regulations require that the system be capable of achieving a maximum 1 foot leachate depth on the bottom of the landfill and be constructed of materials which can withstand the pressures and disturbances (e.g., from the weight of the wastes and cover materials, and equipment used in the landfill).

2. Guidance

Leachate detection, collection, and removal systems should have:

(a) at least a 30 centimeter (12-inch) drainage layer with a hydraulic conductivity not less tnan $1x10^3$ cm/sec and a minimum slope of 2 percent;

(b) a graded granular or synthetic fabric filter above the drainage layer to prevent clogging unless the following criteria are met:

$$\frac{D_{15}\ (\text{waste})}{D_{85}\ (\text{drainage layer})} \leq 5$$

$$\frac{D_{50}\ (\text{waste})}{D_{50}\ (\text{drainage layer})} \leq 25$$

and

$$\frac{D_{15}\ (\text{waste})}{D_{15}\ (\text{drainage layer})} \leq 20$$

(May be as high as 40 where $C_u > 4$)

where:

D_{15} = grain size, in millimeters, at which 15% of the waste or drainage layer media used, by weight, is finer.

D_{50} = grain size, in millimeters, at which 50% of the waste or drainage layer media used, by weight, is finer.

D_{85} = grain size, in millimeters, at which 85% of the waste or drainage layer media used, by weight, is finer.

C_u = the Hazen uniformity coefficient, is the ratio of the diameter at the 60% finer point to that at the 10% finer point on the graduation curve ($C_u = \frac{D_{60}}{D_{10}}$).

(c) A graded granular filter, when present, that meets the following criteria:

$$\frac{D_{15}\ \text{(waste)}}{D_{85}\ \text{(filter media)}} \leq 5$$

$$\frac{D_{50}\ \text{(waste)}}{D_{50}\ \text{(filter media)}} \leq 25$$

$$\frac{D_{15}\ \text{(waste)}}{D_{15}\ \text{(filter media)}} \leq 20$$

(May be used as high as 40 when $C_u > 4$)

$$\frac{D_{15}\ \text{(filter media)}}{D_{85}\ \text{(drainage layer)}} \leq 5$$

$$\frac{D_{50}\ \text{(filter media)}}{D_{50}\ \text{(drainage layer)}} \leq 25$$

$$\frac{D_{15}\ \text{(filter media)}}{D_{15}\ \text{(drainage layer)}} \leq 20$$ (May be as high as 40 where $C_u > 4$)

and to avoid excessive head loss in filter (i.e., to maintain flow through the filter):

$$\frac{D_{15}\ \text{(filter media)}}{D_{15}\ \text{(drainage layer)}} \geq 5$$ (May be as high as 40 where $C_u > 4$)

Where the symbols have the same relative meanings as in paragrapn (b); and

(d) A drainage system that includes:

(1) Drainage pipes or tiles of appropriate size and spacing to efficiently remove leachate and meet the following criteria:

$$\frac{D_{50}\ \text{(drainage layer)}}{PS} \leq 1.0$$

where:

D_{50} = given size in millimeters, at which 50% of the drainage layer media used, by weight is finer.

PS = slat width or hole diameter of the pipe in millimeters, and

(2) A sump pump, gravity discharge or other means to efficiently remove leachate.

3. Discussion

The Agency believes that it is practical to design a leachate collection, and removal system or a leak detection system to maintain leachate depth at one foot or less, except perhaps temporarily during severe storms. The specifications presented here, are expected to accomplish that requirement.

The mimimum thickness (30 centimeters or 12 inches) of the drainage layer is designed to allow sufficient head to promote drainage. The two percent minimum slope is also designed to promote drainage. In most cases, the Agency believes thicker drainage layers and greater slopes will be selected by owners and operators to maximize the efficiency of the leacnate collection, and removal system. The hydraulic conductivity of not less than 1 X 10^{-3} cm/sec was chosen because materials widely used as drainage media are typically at least that permeable. Additionally, where the leachate collection system is used over a secondary clay liner, the specification provides four orders of magnitude difference between the drainage layer and the secondary liner which should have a hydraulic conductivity of not more than 1 X 10^{-7} cm/sec. Data available to the Agency show a significant increase in the efficiency of drainage when a four order of magnitude difference exists.

Drainage tile diameter and spacing are important because they affect the head which builds up on the bottom liner between the tiles. The closer the tiles are together, the less the head. Also, the tile diameter should be large enought to effi-

ciently carry off the collected leachate. Since the philosophy for all aspects of liner design is to minimize liquid transmission through the liner system, the head on the liner should be minimized. But the spacing and size of the tile system necessary to accomplish this depends on other characteristics of the drainage layer (e.g., media hydraulic conductivity) and on the impingement rate of liquids which is a function of precipitation. The Agency is therefore not specifying minimum tile spacing or size in this guidance. However, EPA believes that a design incorporating 4 in. diameter tiles on 50 to 200 foot (15 to 60 meter) centers will effectively minimize head on the liner system. The owner or operator should demonstrate through appropriate design calculations in his application that the one-foot head requirement is being or will be achieved.

The leachate collection, and removal system should also be overlain by a graded granular or synthetic fabric filter. The purpose of this is to prevent clogging of the pores in the drainage layer of the collection system by infiltration of fines from the waste. If a granular filter is used, it is important that the relationship of grain sizes of the filter medium and the drainage layer be appropriate if the filter is to fulfill its function to prevent clogging of the drainage layer and not to contribute to clogging. The guidance specifies a criterion for this purpose which is widely used in construction to prevent clogging (blinding) of drainage media. The criterion was developed by the U.S. Army Corps of Engineers and is used in their engineering manuals.

D. Liner Specifications

1. The Regulations

As discussed in Section B of this guidance, the liner system must be designed and built to achieve containment of fluids during the life of the landfill unit, thus preventing the escape of hazardous constituents to surrounding soils and ultimately to the ground water. At least one liner must be installed, and the material used must be chemically resistant to the wastes and the leachate. The liner must exhibit and be of sufficient strength to withstand the forces it will encounter during installation and operation. In this regard, a base is required which must provide sufficient support to the liner to prevent failure. The liner system must, of course, cover all areas likely to be exposed to waste and to leachate.

2. Guidance

In Section B of this guidance, the Agency identified the conditions under which it believes single and double liner systems are appropriate and the nature of the materials recommended. Following are liner specifications which the Agency believes will produce stable construction and which will prevent the release of hazardous constituents to the maximum extent practicable:

(a) Synthetic liners should:

(1) Consist of at least a 30 mil membrane that is chemically resistant to the waste managed at the landfill. In judging chemical compatibility of wastes and membranes, the Agency will consider appropriate historical data, demonstrations

of chemical resistance of liners should be performed using either the EPA test method attached or an equivalent test method.

(2) Be protected from damage from above and below the membrane, by at least 15 centimeters (6 inches) of bedding material no coarser than Unified Soil Classification System (USCS) sand (SP) and which is free of rock, fractured stone, debris, cobbles, rubbish, roots, and sudden changes in grade. Leachate, collection, and removal systems, soil (clay) liners, or natural, in situ soils may serve as bedding materials when in direct contact with synthetic liners if they meet the requirements specified herein.

(b) Soil liners should:

(1) Consist of at least 60 centimeters (24 inches) of natural or recompacted soil (e.g., clay) with a saturated hydraulic conductivity not more than 1×10^{-7} cm/sec. Saturated hydraulic conductivity testing should be conducted in accordance with the EPA test method attached or an equivalent;

(2) Have a saturated hydraulic conductivity which is not increased beyond 1×10^{-7} cm/sec as a result of contact with the leachate generated at the landfill. Testing of the effect of leachate on soil liner hydraulic conductivity should be performed using either the EPA test method attached or an equivalent test method;

(3) Have no lenses, cracks, channels, root holes, or other structural nonuniformities that can increase the nominal hydraulic conductivity of the liner above 1×10^{-7} cm/sec; and

(4) Where recompacted emplaced soil liners are used, be placed in lifts not exceeding 15 centimeters (6 inches) before compaction to maximize the effectiveness of compaction.

3. Discussion

EPA believes synthetic liners should be at least 30 mils thick. Thinner synthetic membrane liners are can be readily damaged during installation or operation. To guard against damage, it is good practice to protect synthetic liners both from above and below by a minimum of six inches of bedding material. This protects against punctures, tears, and rips due to contact with sharp objects in the waste and damage resulting from dropping wastes on the liner or driving vehicles on an unprotected membrane. The top bedding layer also protects the synthetic membrane from damage due to exposure to sunlight and wind while the cell is in operation. The bedding layer should consist of materials which are no coarser than sand (SP) as defined by the Unified Soil Classfication System (USCS). Use of a sand layer is common practice for protection of membranes. delicate materials from damage due to contact with grading equipment and materials, sharp materials in the soil, etc. The bedding material need not be a separate layer as natural soils or the leachate, collection, and removal system materials will often meet the necessary criteria.

Chemical testing is prudent because all liners can be degraded by specific chemicals which may be present in the waste. Because wastes and liner chemical characteristics are

almost infinitely variable, it is difficult to generalize concerning incompatibility. The Agency therefore prefers test data as the appropriate way to demonstrate the compatibility of waste and liner materials but recognizes that historical data (e.g., results elsewhere with similar wastes) or theoretical chemistry may provide sufficient information in some cases. Data currently available to EPA indicate that the following combinations of waste types and liner materials are often incompatible:

(a) Chlorinated solvents tend to dissolve polyvinyl chloride (PVC).

(b) Chlorosulfonated polyethylene can be dissolved by aromatic hydrocarbons

(c) Clays may exhibit permeability changes when exposed to selected concentrated organics.

(d) Asphaltic materials may dissolve in oily wastes

(e) Concrete and lime based materials are dissolved by acids

(f) Clays inorganic high and low pH

(h) Clays can exhibit permeability changes when exposed to inorganics of high and low pH.

The Agency is currently developing a more comprehensive summary of waste/liner compatibility information which will be included in a later edition of this document.

An acceptable test method for evaluating waste/liner compatibility is incorporated in the appendix to this document. The test method exposes a liner sample to the waste or leachate

encountered at the facility. After exposure, the liner sample is tested for important characteristics--saturated hydraulic conductivity in the case of soil liners; strength (tensile, tear, and puncture) and weight loss in the case of synthetics. The Agency considers any significant deterioration in any of the measured properties to be evidence of incompatibility unless a convincing demonstration can be made that the deterioration exhibited will not impair the integrity of the liner over the life of the facility. Even though the tests may show the amount of deterioration to be relatively small, the Agency is concerned about the cumulative effects of exposure over very much longer periods than those actually tested.

Soil liners will normally be of clay soils. They should have a saturated hydraulic conductivity of not more than 1×10^{-7} cm/sec and be at least 60 centimeters (2 feet) thick. Many clays can readily be recompacted to meet the specified level. It is not clear, however, that recompacting to meet a tighter specification can be routinely accomplished. In concert with the philosophy of these designs, soil liners serve as backup systems and are depended upon to minimize the rate of liquid flow through them. Thickness of the soil is not as important as other factors in minimizing flow but a minimum thickness is necessary to retain structural stability (reduce cracking potential, etc.). Two feet is generally accepted to be a minimum stable thickness for recompacted clay.

Another function of liners is to improve the efficiency of the leachate collection, and removal system. Synthetic membranes typically achieve virtual complete rejection of fluids and are thus most effective. For this reason, they have been as the primary liner. Soil (clay) liners do allow some of the liquid reaching them to enter the pore structure and ultimately escape. For this reason, clay liners are recommended only as a backup in the event the primary liner fails. The tighter the clay layer, the less fluid will seep into it, and therefore, the more fluid will be removed by the collection, and removal system. As is the case with minimization of flow, the thickness of the soil layer is not as important as other factors in determining the leachate rejection efficiency of the liner.

When discussing the relative tightness of soils, the term permeability is most often used. This is a generic term, refering to the property in general. In this guidance, EPA uses the more specific term--"hydraulic conductivity". An acceptable method for soil hydraulic conductivity has been included in the Appendix to this document.

In situ soils can be considered acceptable as soil liner material provided the specifications in this guidance are met. Natural soil liners should be free of conduits and channels which would convey liquids through the liner. This includes root holes, sand lenses, cracks, fractures, etc.

E. Cap (Final Cover) Design

1. The Regulation

The cap or final cover must be designed to minimize infiltration of precipitation into the landfill after closure. It must be no more permeable than the liner system. It must operate with minimum maintenance and promote drainage from its surface while minimizing erosion. It must also be designed so that settling and subsidence are accommodated to minimize the potential for disruption of continuity and function of the final cover.

2. Guidance

(a) The cap or final cover should be placed over each cell as it is completed. In cases where landfills are operated with multiple lifts (cells placed vertically on top of each other), final cover cannot, of course, be placed until the final lift is completed, although interim cover should be added to each cell as it is completed to minimize precipitation inflow. Where possible, when large cells are used, final cover should be placed as filling progresses. This is often possible with trench operations, where filling progresses from one end of the trench to the other.

(b) The cap (final cover) should consist of the following as a minimum:

(1) A vegetated top cover, as described in paragraph (c) of this section;

(2) A middle drainage layer, as described in paragraph (d) of this section; and

(3) A low permeability bottom layer as described in paragraph (e) of this section.

(c) The vegetated top cover should:

(1) Be at least 60 centimeters (24 inches) thick;

(2) Support vegetation that will effectively minimize erosion without need for continuing application of fertilizers, irrigation, or other man-applied materials to ensure viability and persistence. (Fertilizers, water, and other materials may be applied during the closure or post-closure period if necessary to establish vegetation or to repair damage.);

(3) Be planted with persistent species that will effectively minimize erosion, and that do not have a root system that will penetrate beyond the vegetative and drainage layer;

(4) Have a final top slope, after allowance for settling and subsidence, of between three and five percent, unless the owner or operator knows that an alternate slope will effectively promote drainage and not subject the closed facility to erosion. For slopes exceeding five percent, the maximum erosion rate should not exceed 2.0 tons/acre per year using the USDA Universal Soil Loss Equation (USLE); and

(5) Have a surface drainage system capable of conducting run-off across the cap without forming erosion rills and gullies.

(d) The drainage layer should:

(1) Be at least 30 centimeters (12 inches) thick with a saturated hydraulic conductivity not less than 1×10^{-3} cm/sec;

(2) Have a final bottom slope of at least two percent,

after allowance for settling and subsidence;

(3) To prevent clogging, be overlain by a graded granular or synthetic fabric filter that meets the specifications of section C. 2. b. of this guidance; and

(4) Be designed so that discharge flows freely in the lateral direction to minimize head on and flow through the low permeability layer.

(e) The low permeability layer should have two components:

(1) The upper ~~component~~ should:

(A) Consist of at least a 20 mil synthetic membrane;

(B) Be protected from damage below and above the membrane by at least 15 centimeters (6 inches) of bedding material no coarser than Unified Soil Classification System (USCS) sand (SP) and which is free of rock, fractured stone, debris, cobbles, rubbish, roots, and sudden changes in grade (slope). The drainage layer and lower soil (clay) component may serve as bedding materials when in direct contact with synthetic caps if they meet the specifications contained herein;

(C) Have a final upper slope (in contact with tne bedding material) of at least two percent after allowance for settling; and

(D) Be located wholly below the average depth of frost penetration in the area.

(2) The lower component should:

(A) Include at least 60 centimeters (24 inches) of soil recompacted to a saturated hydraulic conductivity of not more than 1 X 10^{-7} cm/sec;

(B) Have the soil emplaced in lifts not exceeding 15 centimeters (6 inches) before compaction to maximize the effectiveness of compaction;

(f) In designing the final cover, owners and operators should estimate and accommodate the amount of settling and subsidence expected as a result of:

(1) The incorporation of containerized liquids prior to the ban imposed March 22, 1982 (47 FR 12316); and

(2) Degradation and long-term consolidation of waste.

3. Discussion

The guidance calls for placing the final cover at closure of each cell or, preferably, as filling of the cell progres In some cases, such as when operations are conducted in multiple lifts, final cover cannot be applied until the top cell is fill Less substantial, interim cover should be applied to other cell in multiple lift landfills.

The Agency believes that a three layer final cover (cap) will adequately minimize infiltration of precipitation, which i the primary purpose of the final cover. The final cover acts t minimize infiltration by causing precipitation to run off throu use of slopes, drainage layers, and impermeable and slightly permeable barriers. By minimizing infiltration, the generation of leachate will also be minimized, thereby reducing long-term discharge of pollutants to the ground water to a bare minimum. To prevent the "bathtub effect," i.e., to prevent the landfill from filling with leachate after closure when the leachate collection system ceases to function, the final cover must be r

more permeable than the most impermeable component of the liner system (or of the underlying soils). In this way, no more precipitation is allowed to infiltrate the cell than can escape through the bottom liner. Prevention of the "bathtub effect" is important to eliminate the possibility of surface overflow or migration through porous surface strata. The latter phenomenon is largely the cause of the problems at Love Canal in New York. Other functions of the final cover include prevention of contamination of surface run-off, prevention of wind dispersal of hazardous wastes, and prevention of direct contact with hazardous wastes by people and animals straying onto the site.

The top layer should have at least two feet of soil capable of sustaining plant species which will effectively minimize erosion. Two feet was chosen because it will accommodate the root systems of most nonwoody cover plantings and is typical practice within the waste management industry today. Species planted should not require continuing man-made applications of water or fertilizers to sustain growth since such applications cannot be guaranteed in the long term. Application of water and fertilizer is, of course, acceptable during the early stages of the post-closure care period as the plant growth is being established. The plant species chosen should also not have root systems which can be expected to penetrate beyond the vegetated and drainage layers. If they penetrate deeper, they can damage the integrity of the low permeability layer.

After allowance for settling and subsidence, the final slop should be at least three percent to prevent pooling due to irreg

larities of the surface and vegetation, but less than five percent to prevent excessive erosion. The Agency recognizes that for some landfills operated with multiple vertical lifts or operated as piles, limiting final slope to five percent may not be practical. Owners and operators using different final slopes should determine that an alternate slope will not be beset with erosion problems and that it will promote efficient drainage. The U.S. Department of Agriculture Universal Soil Loss Equation (USLE) is recommended as a tool for use in evaluating erosion potential. The USLE predicts average annual soil loss as the product of six quantifiable factors. The equation is:

$$A = RKLSCP$$

where
- A = average annual soil loss, in tons/acre
- R = rainfall and run-off erosivity
- K = soil erodibility factor, tons/acre
- L = slope-length factor
- S = slope-steepness factor
- C = cover/management factor
- P = practice factor

The data necessary as input to this equation is described in Evaluating Cover Systems for Solid and Hazardous Waste (SW-867) September 1980, U.S. EPA. The maximum annual rate of erosion for any part of the cover should not exceed 2.0 tons/acre in order to minimize the potential for gully development and future maintenance. The agricultural data base indicates that rates as low as 1/3 ton/acre are achievable for a silt-loam soil, sloped 4 percent with a blue grass vegetative cover. The Agency believes that 2 tons/acre can be more readily achieved

and does not significantly increase cover maintenance. The top layer should also have some means of conducting run-off (e.g., swales or conduits) to safely pass run-off velocities and volumes without eroding the cover.

The second layer or drainage layer is analogous in function to the leachate collection system over the liner. It should be at least 12 inches thick to provide capacity to handle water from major sustained storm events, and should be constructed of porous materials (at least 1 X 10^{-3} cm/sec hydraulic conductivity). Drainage tiles or other collection devices are not necessary. The Agency believes that the combination of very porous media, a final minimum two percent slope after settling, and the impermeable nature of the layer beneath will effectively conduct precipitation infiltrating the vegetative layer off of the landfill. As with the leachate collection system, the drainage layer should be overlain with a graduated granular or synthetic fabric filter to prevent plugging of the porous media with fine earth particles carried down from the vegetated layer. To prevent fluid from backing up into the drainage layer, the discharge at the side should flow freely.

The function of the low permeability layer is to reject fluid transmission, thereby causing infiltrating precipitation to exit through the drainage layer. It should consist of at least two components. The upper component should be at least a 20 mil thick synthetic membrane. While the regulations do not specify that the final cover prevent infiltration, the requirement that it be no more permeable than the bottom

liner, as a practical matter, necessitates the use of a synthetic membrane. This is so because the regulatory requirement for the liner system does specify that leachate be contained and this will be translated, in most cases, into a very nearly impermeable synthetic membrane liner.

The minimum thickness recommended for the synthetic component of the cap (20 mil) is less than that specified for the liner (30 mil) because (1) the cap is not expected to come in contact with chemical leachates which might hasten failure, and (2) once placed, the potential for damage is small as compared to the potential for bottom liner damage where waste is placed on the liner throughout the operating life of the cell. While intact (30 + years in the absence of damage), the synthetic component will essentially prevent transfer of precipitation through it and leachate production should be very nearly zero. As with liners, synthetic caps should be protected from punture and tears by at least six inches of bedding materials In most cases, the drainage layer media above the synthetic cap, together with the soil (clay) liner under it, can effectively function as the bedding material.

Even with protection from damage, the synthetic cap will not last forever. At some point in the future, the synthetic membrane will degrade. At that time, the function of minimizing infiltration will fall to the second component, a 2-foot minimum clay soil cap with a maximum hydraulic conductivity of 1 X 10^{-7} cm/sec. Although some small amount of precipitation will seep through this secondary cap, the amount of leachate

generated will be quite small and escape to ground water should be minimal. Unless damaged or affected by differential settlement, the secondary soil layer should remain intact and effective into the distant future. One source of damage that can disrupt the continuity of the impermeable layers is frost heaving. For this reason, the impermeable layer should be wholly below the average depth of frost penetration in the area. In some parts of the country meeting this requirement will necessitate a thicker cap than would otherwise be necessary.

One of the more difficult problems associated with designing final cover for landfills is how to allow for settlement especially differential settlement. Settlement occurs as a result of natural compaction and consolidation and biological degradation of organics. It can to be uniformly distributed and can occur before or shortly after closure. Differential settlement is unevenly distributed and can cause disruption in continuity of the final cover. One cause of differential settlement is the collapse of drums which have released liquids. Settlement from this source may not occur for a number of years following closure. For new landfills and for new cells not located over existing cells, subsidence due to drum collapse should not be a problem. As of March 27, 1982, liquids in containers have been essentially banned from landfills (47 FR 12316).

EPA intends to develop specific design requirements which will ensure adequate allowance for settlement. As of this writing, however, the Agency lacks sufficient information to judge the effectiveness of various design options. Therefore,

this guidance suggests simply that owners and operators estimate the amount of subsidence and allow for it in the final cover desig: as best they can. The final result should be a minimum three percent final slope after settling and subsidence. During the post-closure period, the regulations require that disruption of the continuity and slope of the final cover be repaired. The owner or operator must allow for subsidence and settling in the facility design. As the Agency evaluates alternative methods of designing final cover to effectively allow for settling and subsidence, it will issue further guidance or perhaps even regulations covering the subject.

One suggestion which owners and operators may consider as a means of at least partially accomodating settling and subsidence, is to stage final closure and the placement of the final cover. Field data indicates to EPA to that most settlment problems occur soon after closure. It may be preferable delay placement of the final cover for six months or more in those cases where substantial subsidence or settlement are expected. By so doing, expensive repairs to the final cover may be avoided. This would require an extension in the 180 day limit to the closure period imposed in Subpart G. In deciding whether to grant such an extension in accordance with the rules of Subpart G, the permitting official will normally require installation of an expendable interim cover, capable of minimizing precipitation migration into the landfill, unless

it is clear that the liner and leachate collection systems are functioning and are expected to continue to function during the extended closure period. The Agency solicits information on the effectiveness of this and other approaches to dealing with the settling/subsidence problem.